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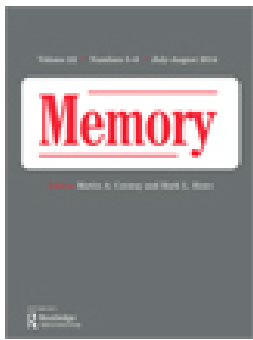
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# Olfactory cues are more effective than visual cues in experimentally triggering autobiographical memories

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## ABSTRACT

Folk wisdom often refers to odours as potent triggers for autobiographical memory, akin to the Proust phenomenon that describes Proust's sudden recollection of a childhood memory when tasting a madeleine dipped into tea. Despite an increasing number of empirical studies on the effects of odours on cognition, conclusive evidence is still missing. We set out to examine the effectiveness of childhood and non-childhood odours as retrieval cues for autobiographical memories in a lab experiment. A total of 170 participants were presented with pilot-tested retrieval cues (either odours or images) to recall childhood memories and were then asked to rate the vividness, detail, and emotional intensity of these memories. Results showed that participants indeed reported richer memories when presented with childhood-related odours than childhood-related images or childhood-unrelated odours or images. An exploratory analysis of memory content with Linguistic Inquiry and Word Count did not reveal differences in affective content. The findings of this study support the notion that odours are particularly potent in eliciting rich memories and open up numerous avenues for further exploration.

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## KEYWORDS

Scent; olfaction; odour; autobiographical memory; Proust



The link between olfaction and cognition has been receiving a growing amount of attention. Olfactory cues are ubiquitous in our daily lives, but we have only limited understanding in how they affect our cognitive processes. Studies into potential effects of odours on cognition have shown that odours may influence, among others, consumer spending behaviour (Chebat & Michon, 2003), product quality judgments (Bone & Jantrania, 1992), behavioural intention, and actual behaviour in a non-conscious manner (Holland, Hendriks, & Aarts, 2005) as well as language, attention, and general cognitive functioning (Westervelt, Ruffolo, & Tremont, 2005). Our research focuses on the link between olfaction and memory. Research on olfactory memory spans topics such as olfactory processing, olfactory recall and imagery, duration of olfactory memory, implicit memory for odours, odour-based context-dependent memory, odour-evoked olfactory memory, and the affective influence of odours (for an overview, see Herz & Engen, 1996; see also Herz, 2016).

The attention for olfactory memory resonates with popular wisdom that odours are potent reminders of past experiences. This popular wisdom was bolstered by the 1913 publication of Marcel Proust's *À la recherche du temps perdu*, in which he described a similar experience. However, direct empirical support for the close link between olfaction and memory is scarce (Chu & Downes,

2000a, 2002; Jellinek, 2004). While a number of studies have been carried out, we argue that previous methodological constraints inherent in those studies mean that a conclusive empirical assessment is not yet available. We therefore set out to empirically test whether odours are more effective than visual cues for eliciting autobiographical memories (AMs). AM is defined here as personally experienced events (Conway & Pleydell-Pearce, 2000). We first clarify approaches to testing the link between memory and olfaction, and identify three critical challenges in testing the potency of olfactory AM cues.

## Different approaches to the link between memory and olfaction

One problem with testing the link between olfaction and AM is that there is no consensus on the definition of what constitutes the phenomenon of olfactorily cued recall. The relationship has often been described as the Proust phenomenon (Chu & Downes, 2002), although the original episode detailed by Proust focused on taste, not scent. Rubin, Groth, and Goldsmith (1984) describe the link as a belief that odours evoke memories that are older than memories evoked by other cues and there is a significant body of research that supports this notion. For example, a large number of studies have shown that

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odour-evoked memories tend to be from the first decade of participants' lives, while memories triggered by other sensory modalities tend to be from early adulthood (e.g., Chu & Downes, 2000b; Larsson & Willander, 2009; Miles & Berntsen, 2011; Willander & Larsson, 2006, 2007, 2008).

A second interpretation of the link between memory and olfaction is offered by Engen and Ross (1973), who see the relationship as the belief that odours are forgotten more slowly than memories of other sensory modalities. This prediction is further supported by neuroanatomical research demonstrating that odour-invoked memories originating in childhood are related to stronger activation of the secondary olfactory cortex, whereas odour-invoked memories originating from young adulthood lead to activation in the left inferior frontal gyrus (supporting semantic memory processing; Arshamian et al., 2013). This differential brain activation for odour-invoked memories of different ages lends support to the notion that old, olfactory memories are encoded differently and may be subject to different processes of retrieval and decay.

Herz and Cupchik (1995) state that memories triggered by olfactory cues are more emotionally loaded, which would be the core of the relationship between olfaction and memory. Their definition is supported by the findings of Herz (2004) that participants who were asked to retrieve positive memories using perfume showed stronger neural activation in the amygdala and hippocampal regions than participants who were asked to recall memories using images of the same perfume. In a similar study by Arshamian et al. (2013), odour-evoked memory retrieval, compared to verbal-induced memory retrieval, also leads to activation of a different region in the limbic system (see Ehrlichman & Bastone, 1992 and Willander & Larsson, 2006 for a critical assessment of the odour–emotion link).

One commonly accepted definition is that of Chu and Downes (2000a), who have summarised the differences above by stating that the phenomenon refers to an odour's ability to trigger old memories that are affectively intense and highly vivid. According to Chu and Downes, a test should thus seek to demonstrate that olfactory retrieval cues outperform retrieval cues of other sensory modalities in terms of eliciting memories that are *older*, more emotionally *intense*, and more *vivid*. This interpretation of the phenomenon is in agreement with Larsson, Willander, Karlsson, and Arshamian's (2014) statement that odour-invoked AM is characterised as limbic, old, vivid, emotional, and rare (acronym LOVER). However, Jellinek (2004) has criticised Chu and Downes for oversimplifying the phenomenon, stating that a true test should focus on confirming a larger number of hypotheses. For example, Jellinek stresses that Proust describes how the recalled memory is preceded by surprise and that this surprise prompts the search for the memory, which is difficult to assess methodologically. Also included in the hypotheses formulated by Jellinek is that awareness of emotions precedes awareness of the sensory stimulus and that awareness of physiological activation precedes awareness of the memory. Since

these cognitive events occur in quick succession, testing their order of occurrence would require elaborate neurological measurements of an individual's response to odour cues. We therefore limit the present study to the more accessible variables.

In sum, different interpretations of olfactorily cued recall emphasise different aspects of the phenomenon but generally agree that odour-evoked AMs tend to be older and qualitatively richer than AM evoked by cues of other sensory modalities. The current study seeks to test that last prediction.

### **Methodological difficulties in testing the link between olfaction and AM**

Aside from ambiguities in defining the phenomenon, research into its existence is hampered further by methodological challenges. These challenges include the targeting of the correct type of memory, the person-specific nature of odour–memory associations, and the elimination of alternative hypotheses. We review previous studies to identify strategies to overcome these challenges.

#### **Challenge #1: Targeting naturalistic AMs**

One of the most common problems is targeting genuine naturalistic AMs. A large body of odour–memory research consists, for example, of context-dependent memory studies. These studies typically provide participants with target information (most often a text or a list of words) to remember while exposing them to peripheral stimuli such as ambient fragrances and later examine the effectiveness of the same peripheral cue by registering how much of the original information is recalled. Such studies have found that participants indeed remember information better when they receive the same odour as retrieval cue (Parker, Ngu, & Cassaday, 2001), that this effect is augmented by salience of the odour (Herz, 1997), and that performance is better when participants receive odour cues compared to visual cues (Pointer & Bond, 1998). In short, studies find that peripheral information such as odour is encoded along with the target information and can be used as an effective retrieval cue. Though in line with the general importance of olfactory cues, it does not test the effectiveness of odour in triggering AM, because context-dependent studies generally focus on semantic, not episodic, memories that constitute personally relevant AMs (Tulving, 1972). Our study should therefore target episodic instead of semantic memory.

In research on odour and episodic memory, active association presents a new problem for the targeting of genuine and naturalistic AM. Herz and Cupchik (1995), for example, asked participants to memorise emotional paintings using either words or odours. After being asked to describe the paintings later, they found that participants who received odour cues reported more emotional recollections of their experience than those without odour cues. While this finding is in line with Chu and Downes'

(2000a) link between odour and highly affective memories, it is important to realise that the association between odour and the target experience in the study by Herz and Cupchik was created very intentionally. Naturalistic AMs, on the other hand, are generally created by a passive encoding process without the individual intentionally associating peripheral details with the central event (Chu & Downes, 2002). Additionally, by providing participants with target information, studies such as the one by Herz and Cupchik examine recall of memories that are very recent, whereas the Proust phenomenon refers to memories that can be decades old (Jellinek, 2004). Intentionally paired odours and memories therefore cannot provide a critical test whether odour cues trigger more emotional naturalistic AMs than other cues.

Chu and Downes' (2002) side-stepped active association by asking participants to report AMs for each of five auditorily presented odour labels and then asked them to indicate how old, vivid, and emotionally intense these memories were after being presented with a visual odour label, an odour congruent or incongruent with that odour label. The authors showed that reported affect and detail were higher and age at the time of memory was younger in the congruent odour condition. In a second study, they compared odour labels, (in)congruent odours, and photographs and found that the congruent odour cues led to more detailed memory descriptions. Chu and Downes (2002) suggest that the two studies provide evidence that olfactory cues are particularly effective for AM recall. A similar study was conducted by Herz and Schooler (2002) in which participants selected a naturalistic childhood memory after being presented with a verbal label and were then given verbal, visual, or olfactory cues to aid in the retrieval of the selected memory. Results showed that participants presented with the olfactory cue reported more emotional memories and a stronger sense of being "brought back" to the event. While both Chu and Downes' (2002) and Herz and Schooler's (2002) studies indeed target naturalistic AM, memories may not necessarily be meaningful: participants in Chu and Downes' study were asked to report any memories they had about five presented odorous objects, such as parmesan cheese, lemon, and ginger. In Herz and Schooler's study, odours included crayons, sunscreen, and play-doh. One can wonder if asking participants to recall memories associated with one or more seemingly random odour objects can generate personally highly relevant memories akin to the memory described by Proust.

To our knowledge, there is only one study that has tested the potency of odour as a retrieval cue of meaningful naturalistic AMs. Aggleton and Waskett (1999) conducted a study among visitors of a Viking museum, which used fragranced displays. They asked 45 visitors to report what they remembered of the Viking displays (average time since the last visit was 6.7 years) with the aid of a congruent odour cue, incongruent odour cue, or no odour cue. The results were in the expected direction

(higher means for the congruent odour condition), but the low sample size meant the study was not sufficiently powered to test the effect. Odour-memory connections were also recent and selected by the researchers, not the participants themselves. In addition, odour cues were not compared against cues of other sensory modalities. Therefore, an appropriate test ought to examine differences between retrieval cues of different modalities with regard to their potency to trigger meaningful naturalistic AMs.

### **Challenge #2: Odour-memory associations are unique and person-specific**

The original memory experience as described by Proust details how a specific olfactory cue (i.e., a morsel of a *petit madeleine* dipped in tea) unexpectedly and powerfully triggers an equally specific memory (i.e., Proust's aunt Leoní giving him the same cake on Sunday mornings) which had been considered forgotten. Clearly, the combination of cue and memory in this example is highly personal and applies only to Proust himself. Any other person would likely have eaten the cake without encountering a detailed and emotional experience. This uniqueness creates the second challenge: by their very nature, meaningful naturalistic AMs are personal and different for each individual. Similarly, odour-memory associations are different for every individual. This makes the Proust phenomenon ill-suited for empirical testing in a standardised setting. Barring extensive and costly a priori research into the personal history of each individual participant, researchers have no way of knowing in advance which odours may evoke strong and meaningful AMs in participants. Additionally, specific odours may be highly complex and difficult to be reproduced (e.g., the smell of a hallway in a childhood home). Furthermore, using different odours for each participant is a risk for standardised experimental designs. A single odour that triggers meaningful AM in all participants is unattainable and a study into the phenomenon exactly as it is described in *Swan's Way* (Proust, 1928/1956) therefore seems impossible. However, we suggest that a close approximation of the phenomenon may be attainable. While it may not be realistically possible to identify a specific odour that will evoke meaningful naturalistic AMs in everybody, it is perhaps possible to identify odours that may evoke such memories to a sufficient degree in multiple people. After all, some odours may be more salient, may be encountered more often, and may be more likely to be associated with life events than other odours. By identifying which odours may trigger meaningful AMs in a group of people rather than in all individuals, the relationship between olfaction and memory can be studied as closely as possible.

When searching for suitable odours that multiple people will associate with life events, it is important to consider how to target memories of personal significance and of relevance for formative memories (see challenge #1). Childhood memories may be good candidates for that purpose as they are generally experienced as highly

relevant and are related to current goals and motives (Singer & Salovey, 1993).

### Challenge #3: Alternative hypotheses and confounding effects

A third challenge concerns alternative explanations for results. For instance, the effects of olfactory retrieval cues may be driven by the thought of the odorous object rather than the odour itself (Chu & Downes, 2002). Studies often employ familiar and easily recognisable odours and recognition of an odour will likely also activate the cognitive concept of the odorous object. As a result, there can be uncertainty about the underlying mechanism behind the memory retrieval: the presented odour or the activated concept of the odorous object. Since the activation of a familiar and easily recognisable odorous object can occur almost instantaneously, it can be difficult to disentangle the two rival explanations. However, a solution may lie in recognition and awareness of the odorous object as key elements in the alternative explanation. While avoiding recognition and awareness of the object altogether (i.e., by using unfamiliar odours) is unadvisable and likely to increase error in the study, adding a verbal label condition will establish a baseline against which the odour cue condition can be compared (Chu & Downes, 2002). Alternatively, awareness and recognition in an experimental setting can be kept constant in all conditions by making the participant explicitly aware of the object *before* presenting them with the odour cue. This process is referred to as the double-cueing methodology (Chu & Downes, 2002; Herz & Schooler, 2002) and simply consists of presenting the participant with an odour label, asking them to report an AM related to this label and then asking them for further detail of that memory after presenting them with an odour cue (or a cue of another sensory modality). Because the participant is made explicitly aware of the odorous object in the first phase of the approach, any differences found between the conditions in the second phase can no longer be attributed to awareness. With the double-cueing methodology, a study of odour-elicited AM changes from asking “can odours elicit AMs?” to “can odours elicit AMs *above and beyond awareness of the object?*”

The abovementioned double-cueing method also addresses a second alternative explanation for the assertion that olfactory cues are particularly potent as reminders of AM. This second explanation, put forth by Chu and Downes (2000a, 2002), is referred to as the *differential encoding bias hypothesis* and postulates that AMs triggered by odours are inherently different from AMs triggered by cues of other modalities in terms of complexity and detail. In other words, it argues that higher ratings of detail and vividness found in previous studies may not be due to the effectiveness of odour as a retrieval cue, but to differences in the underlying memories. According to Chu and Downes (2000a, 2002), this can occur because AMs are complex memories and complex

memories encode more peripheral information. Because odours generally are peripheral information (olfactory details are rarely the central event; Baddeley, 1982), odours are generally encoded in complex memories and not in simple memories. Because odours are associated with more complex memories, Chu and Downes argue, using them as a retrieval cue may lead to more reported details. Cues of other modalities (e.g., visual) are more likely to be encoded in less complex memories and may thus yield less detail. By suggesting that the targeted memories differ, rather than the effectiveness of the cues, the differential encoding bias hypothesis provides an alternative explanation. However, by using the double-cueing method, the target memory is determined before the retrieval cues are presented. The sensory modality of the cue thus has no impact on the selected memory. The double-cueing method is able to eliminate both alternative explanations and was therefore adopted.

### The present study

The current study seeks to provide a direct test of the link between olfaction and memory by applying the double-cueing methodology (Chu & Downes, 2002; Herz & Schooler, 2002). We seek to address limitations of previous studies by specifically targeting meaningful, naturalistic AMs. For that end, we conducted a pilot study after which we selected odours that people predominantly associate with life events from their childhood. In the main study, we then compared the selected odour cues with cues of other modalities to test if odour-evoked memories are qualitatively richer.

*Hypothesis:* Participants who receive olfactory retrieval cues will report qualitatively richer memories, compared to participants who receive visual retrieval cues or no retrieval cues.

Because this study specifically targets AMs that originated during childhood, we do not test predictions concerning differences in age.

## Method

### Pilot study

In order to identify which odours are salient, familiar and strongly related to childhood, 17 students and staff members of a Dutch university were presented with 10 odours. Five of these odours were chosen as commonly encountered odours during childhood. Some childhood odours were selected because previous research by Reid, Green, Wildschut, and Sedikides (2015) showed they were effective triggers of nostalgia, others because they are especially familiar for the targeted Dutch sample.<sup>1</sup> The five selected childhood odours were peanut butter, baby powder (perfumed, brand: Zwitsal), Vicks VapoRub, cinnamon, and lavender. The other five were selected to be non-childhood related and were previously used in



studies by Chu and Downes (2002): coffee, vinegar, sunscreen, lemon, and onion. Participants were presented with these 10 odours in random order. Odours were presented in metal cylindrical containers with perforated lids that allowed the participant to smell the odour without viewing the content. The containers were identical, save for their labels A to J. For each container, participants were asked to identify the content and to report on a 5-point Likert scale how strongly they associated this odour with childhood (1 = not at all associated, 5 = strongly associated).

Results of the pilot study are displayed in Figure 1. In the group of childhood-related odours, VapoRub was identified as both most easily recognisable (82.35% of participants identified the odour correctly) and most strongly associated with childhood ( $M_{\text{VapoRub}} = 4.12$ ,  $SD = 1.05$ ). In the group of non-childhood-related odours, coffee and vinegar were most often correctly recognised (both 64.71%), but vinegar was least associated with childhood ( $M_{\text{vinegar}} = 1.44$ ,  $SD_{\text{vinegar}} = 0.61$ ;  $M_{\text{coffee}} = 1.94$ ,  $SD_{\text{coffee}} = 1.10$ ). Planned contrasts showed that VapoRub was more strongly associated with childhood than all other childhood odours ( $t(30.76) = 3.53$ ,  $p = .001$ ) and vinegar was less associated with childhood than all other non-childhood odours ( $t(61.51)$ ,  $p < .001$ ). Hence, VapoRub and vinegar were selected for the main study.

Participants seemed to have trouble identifying the content of the containers. For most odours, recognition rates were relatively low (overall  $M_{\text{recognition}} = 48.24\%$ ,  $SD = 21.26$ ), even though odours were selected specifically for being easily recognisable. However, awareness of the odour is an important alternative explanation for odour-cued retrieval and the pilot test thus illustrated the necessity to avoiding confusion about the content of the

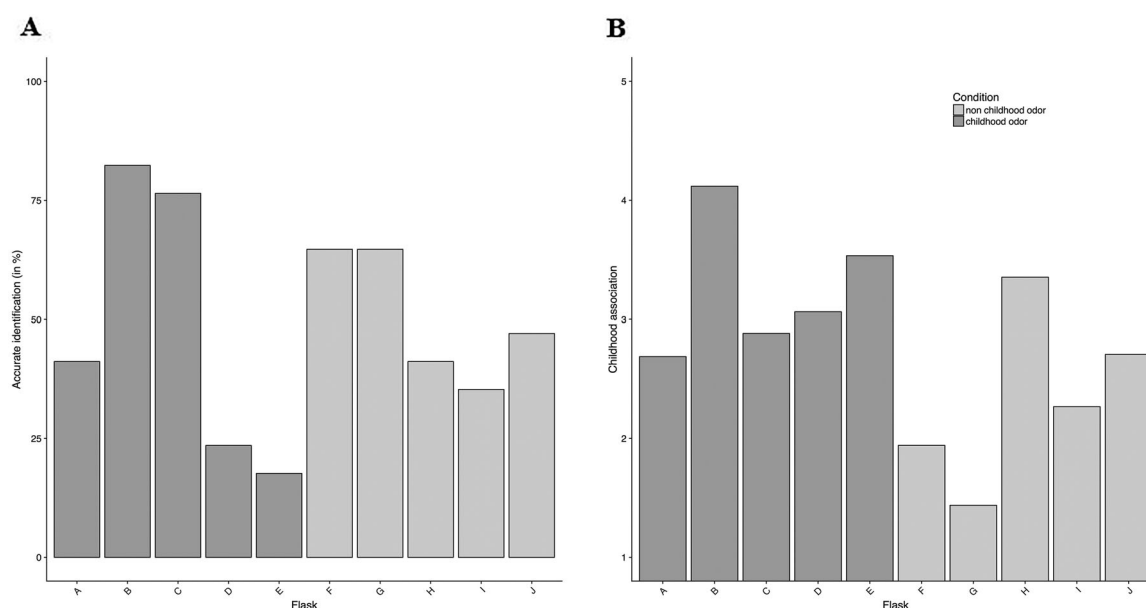
containers during the main study.<sup>2</sup> Despite low recognition rates, the association with childhood was as expected, with  $M_{\text{childhood odour}} = 3.26$  ( $SD = 0.57$ ) and  $M_{\text{non-childhood odour}} = 2.34$  ( $SD = 0.73$ ). This trend was also true for odours with very low recognition rates. For example, with an accuracy of 17.65%, Zwitsal baby powder had the lowest recognition rate of all odours used in the pilot study. Yet, its association score with childhood was  $M = 3.53$ , which is well above the average of childhood odours and the second strongest childhood association overall. This finding suggests that it is the odour itself, rather than cognitive awareness of the odour, that drives the odour–childhood association. However, since the pilot was not designed to test this hypothesis and the sample size was not large enough to allow for significance testing, no conclusions can be drawn concerning the (absence of) effects of recognition on association strength.

## Participants

For the main study, 170 undergraduate psychology students from a Dutch university (35 males,  $M_{\text{age}} = 20$ ) participated for partial fulfilment of a course requirement. A priori power analyses revealed that a sample of 200 participants was necessary in order to obtain sufficient power ( $1 - \beta = 0.80$ ) in a study expecting a conservative small to medium effect size ( $f = 0.20$ ). This target sample size was approximated, but not fully obtained.

## Design

In order to test if participants will report odour-cued AMs of higher quality when presented with an odour cue, a  $2 \times 2 \times 2$  mixed factorial design was used, measuring sensory



**Figure 1.** Pilot results. Image A (left) shows the percentage of accurate identifications of the odour. Image B (right) shows childhood association ratings on a 5-point Likert scale. Flasks used in the pilot contained peanut butter (A), VapoRub (B), cinnamon (C), lavender (D), Zwitsal baby powder (E), coffee (F), vinegar (G), sunscreen (H), lemon (I), and onion (J).

modality (between subjects factor: visual cue vs. odour cue) as well as cue type (within subjects factor: childhood cue vs. non-childhood cue) and controlling for cue order (between subjects factor: childhood cue presented first vs. childhood cue presented last). Additionally, half of the participants (irrespective of the condition they were assigned to) were asked for pre-cue measurements, thus creating a no-cue baseline which allowed for comparison with the two sensory modality conditions.<sup>3</sup>

## Materials

Based on the results of the pilot, VapoRub and vinegar were used as childhood cue and non-childhood cue, respectively. For participants who were assigned to the odour condition, these cues were presented to them in the same metal cylindrical containers that were used in the pilot. The containers were placed under the desk inside the test cubicle in such a way that they would not be visible until the participant was instructed to look for them. The containers were placed in resealable plastic bags to keep the fragrances from dissipating inside the cubicle and potentially invalidating the results. Odour samples were refreshed every 4 hours (1 teaspoon of VapoRub and 10 cc of vinegar absorbed by a single cotton pad). The containers were clearly labelled to ensure that participants could identify the content.

Participants assigned to the visual cue condition were not instructed to look for the containers, but were instead shown a 10 cm by 10 cm picture of either a bottle of vinegar or a jar of VapoRub, displayed in the centre of a computer monitor. In both images, the product labels on the jar/bottle were clearly visible and readable to ensure that all participants were able to identify the object.

After being presented with cues, participants were asked to describe their memory in a text box with the following instructions: "Describe your childhood memory in the box below. Add as much detail as possible; the number of words you can use is unlimited". Furthermore, the quality of the elicited memory was measured using three 7-point Likert scale questions where they were asked to indicate the extent to which they would describe their memory as vivid/detailed/emotionally intense (with 1 = not at all vivid/lively/emotional and 7 = very vivid/detailed/emotional).

All items and instructions were presented to the participants through an online questionnaire. Since the sample was recruited from a population of Dutch students, all materials were presented in Dutch.

## Procedure

The study was conducted by five research assistants, all of whom received a detailed script for standardising purposes. All participants were welcomed and seated in individual cubicles, where they received instructions about

the general lab procedure.<sup>4</sup> Next, participants received instructions about the current study on screen and gave informed consent. Regardless of the condition, all participants were asked to recall and briefly describe a childhood memory for both VapoRub and vinegar. Afterwards, 50% of participants were asked to answer the three Likert scale questions about both memories in order to generate a baseline measurement. The remaining 50% instead read a short line of instructions introducing the subsequent questions. Next, all participants were randomly sorted into either odour or visual cue conditions and received their first cue. Participants in the odour cue condition were instructed to look for the container placed under the desk, smell the content, and put the container back inside the bag before continuing to the questions. Participants in the visual conditions viewed an image for 10 s, before continuing to the questions. Due to counterbalancing, 50% of the participants received the VapoRub cue, while the other half received the vinegar cue. After the cues were presented, all participants were asked to describe their memory concerning that cue in as much detail as possible. They also indicated the vividness, emotional ladenness, and detail of their memory. The same procedure was then repeated for the second memory. After completing the second memory description, participants were asked to answer demographic and control items. Participants were asked what they thought the purpose of the study was, whether they had encountered problems during the procedure, if they had any difficulties retrieving memories, and whether they had noticed an odour in the cubicle upon entering. Finally, participants were thanked and debriefed.

## Results

### Data preparation and reliability analysis

Inspection of the control items revealed that 15 participants reported having detected an odour in the cubicle upon entering; a binary control variable (*noticed scent*) was created to control for potential effects of odour detections. Furthermore, six participants misunderstood the instructions. Four participants had smelled the vinegar and VapoRub containers in the wrong order; their answers for the two memories were switched prior to the analysis. Another participant mistakenly smelled the VapoRub container twice and subsequently had no vinegar memory; this participant's data for the non-childhood odour cue (vinegar) were dropped. Lastly, one participant reported a memory not associated with the VapoRub retrieval cue; this person's data for the childhood cue were dropped.

We inspected the internal consistency of the remaining dataset. The measures of vividness, emotional ladenness, and detail were strongly correlated. Reliability analyses yielded all Cronbach's  $\alpha$ s  $\geq 0.82$ . The items were collapsed



and averaged to create a single variable reflecting memory quality.

In order to compare the memory quality in different cue conditions, scores were collapsed across the pre-cue measurement condition. To this end, a potential carry-over effect of the pre-cue measurement was examined. *T*-tests revealed no such effect (*p* values ranging from .06 to .80).<sup>5</sup> We therefore merged the scores of pre-cue participants with the other participants.

### Main analysis

Comparison of the three cue conditions (no cue, odour cue, and visual cue) showed that means were in the hypothesised direction (see Table 1 for descriptives). For all variables (except *detail*) in the non-childhood cue condition, means in the odour condition were higher than in the no-cue condition and visual condition. In order to test the hypothesis, a repeated-measures analysis (controlling for *noticed scent*) was used to examine differences between the cue and no-cue conditions. Secondly, an ANOVA (again controlling for *noticed scent*) was used to examine differences between the odour and the visual cue.

Repeated-measures analyses on the composite variable (including *detail*, *vividness*, and *emotional intensity*) revealed that participants in the cue conditions reported a higher memory quality than participants in the no-cue condition ( $F_{\text{childhood cue}}(1, 82) = 49.73, p < .001$  and  $F_{\text{non-childhood cue}}(1, 83) = 35.49, p < .001$ ; see Figure 2). More importantly, an ANOVA (controlling for odour detection in the cubicle) showed that participants who received the

childhood odour reported memories of higher quality than participants who received the childhood image ( $F(1, 165) = 4.29, p = .04, \eta^2_{\text{partial}} = 0.03$ ). This effect was not found for participants who received the non-childhood cue ( $F(1, 165) = 0.79, p = .79, \eta^2_{\text{partial}} < 0.01$ ). Thus, results show that recall of a childhood memory is aided by an odour cue only when this odour cue is associated with childhood (congruent) (Figure 3).

### Linguistic Inquiry and Word Count analysis

In order to verify the robustness of the above effect, detailed descriptions of both childhood memories were processed with the Dutch version of the Linguistic Inquiry and Word Count (LIWC) programme (Pennebaker, Francis, & Booth, 2001; Tausczik & Pennebaker, 2010). This LIWC programme counts words to analyse the content of texts, based on the assumption that an angry text, for example, will contain more angry word stems. As the incidence of word stems in a text increases, so does its variable score. LIWC 2001 variable scores are expressed as percentages to reflect the incidence of counted hits, relative to the total word count. Results of the LIWC analysis are presented in Table 1. Fifteen participants used the memory description box to report that they could not think of an appropriate childhood memory. These participants' descriptions were set to missing and were not used in the LIWC analysis.

Because the percentage scores in the LIWC output were strongly skewed, they were log transformed before further analysis. For both the childhood and the non-childhood cues, *t*-tests revealed no differences between the visual and odour cue conditions in terms of affect ( $t_{\text{childhood cue}}(168) = -0.39, p = .70$  and  $t_{\text{non-childhood cue}}(168) = -1.24, p = .22$ ), positive emotion ( $t_{\text{childhood cue}}(168) = 0.00, p = 1$  and  $t_{\text{non-childhood cue}}(168) = -1.78, p = .78$ ), or negative emotion ( $t_{\text{childhood cue}}(168) = -1.00, p = .32$  and  $t_{\text{non-childhood cue}}(168) = -0.48, p = .63$ ).

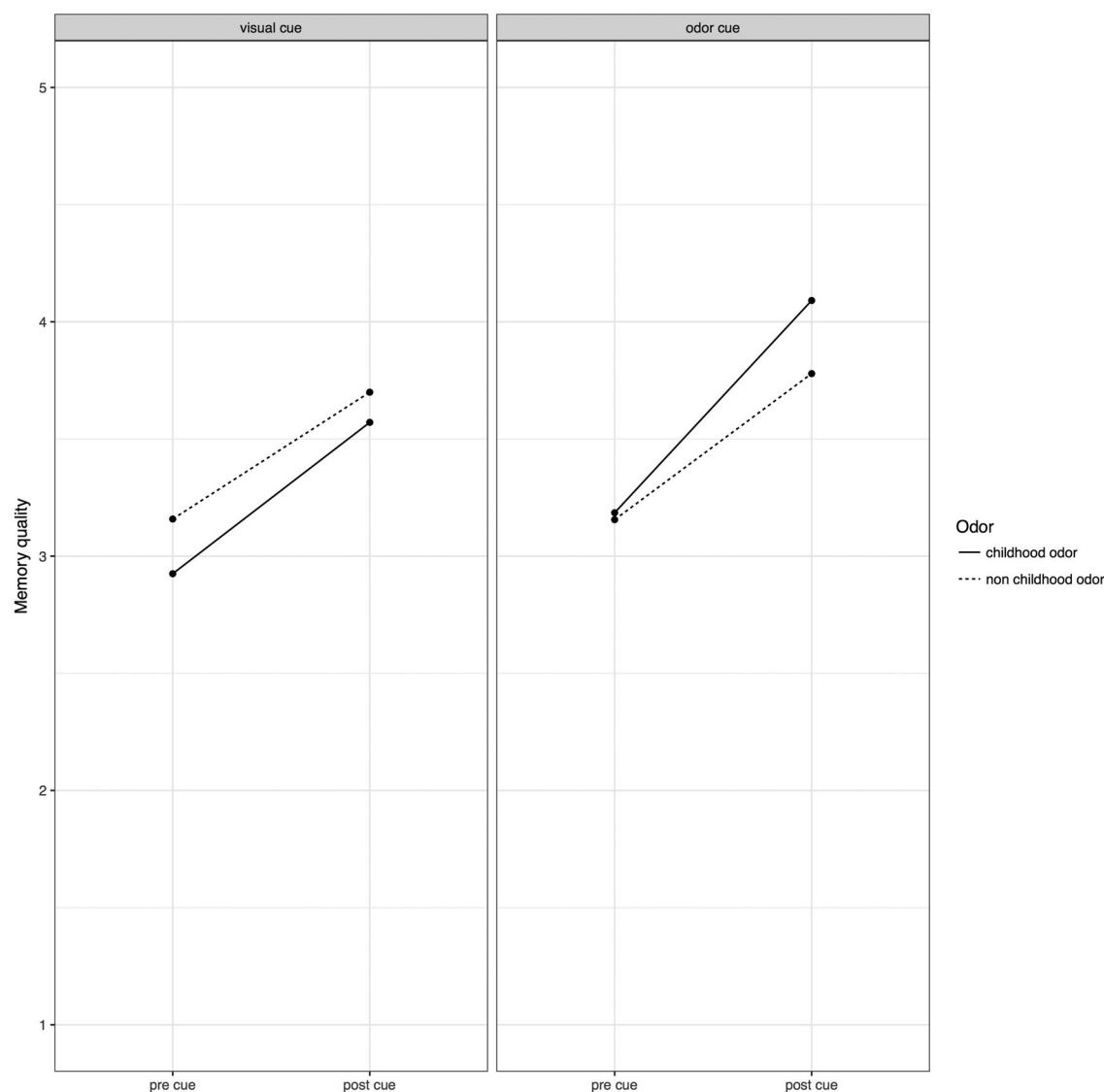
### Discussion

The current study set out to outline how previous challenges in testing the link between olfaction and AM can be overcome and examined whether odour cues are more potent than visual cues in eliciting high-quality AMs (see Chu & Downes, 2000a). We set out to compare the recollection of childhood AMs that were triggered by olfactory cues (childhood congruent/incongruent) compared to images of the same cues. Results of the current study indicate that olfactory cues indeed yield richer childhood AMs, compared to visual cues. This effect was found only when the odour was congruent: non-childhood odours did not affect the reported quality of childhood memories. While participants who received a childhood odour (VapoRub) reported more emotional intensity, they did not write more emotionally toned memory descriptions of these memories.

**Table 1.** Descriptives.

Likert items per condition	No cue ( <i>n</i> = 85) <i>M</i> ( <i>SD</i> )	Visual cue ( <i>n</i> = 80) <i>M</i> ( <i>SD</i> )	Odour cue ( <i>n</i> = 88) <i>M</i> ( <i>SD</i> )
<i>Childhood scent (VapoRub)</i>			
Vivid	3.28 (1.77)	3.85 (1.92)	4.58 (1.57)
Detailed	3.15 (1.79)	3.75 (1.87)	4.18 (1.77)
Emotional	2.75 (1.68)	3.11 (1.75)	3.51 (1.58)
Composite score	3.06 (1.58)	3.57 (1.63)	4.09 (1.41)
<i>Non-childhood scent (Vinegar)</i>			
Vivid	3.66 (1.92)	3.98 (1.82)	4.20 (1.84)
Detailed	3.26 (1.77)	4.11 (1.71)	4.05 (1.83)
Emotional	2.55 (1.55)	3.01 (1.61)	3.09 (1.60)
Composite score	3.16 (1.51)	3.70 (1.46)	3.78 (1.56)
LIWC categories per condition		Visual cue ( <i>n</i> = 89) <i>M</i> ( <i>SD</i> )	Odour cue ( <i>n</i> = 81) <i>M</i> ( <i>SD</i> )
<i>Childhood scent (VapoRub)</i>			
Affect		2.85 (2.75)	2.68 (2.27)
Positive emotion		1.31 (1.62)	1.23 (1.49)
Negative emotion		1.41 (2.18)	1.36 (1.48)
<i>Non-childhood scent (Vinegar)</i>			
Affect		1.72 (2.02)	2.00 (2.01)
Positive emotion		0.67 (1.05)	0.94 (1.19)
Negative emotion		0.99 (1.53)	1.00 (1.32)

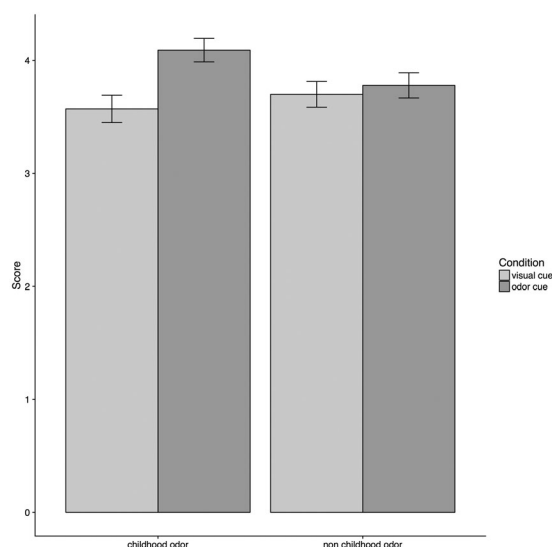
Notes: Baseline participants did not write a detailed description of both their memories during the pre-cue measurement. Therefore, no LIWC data on pre-cue measures exist. Sample sizes between Likert and LIWC measurements differ as a result of missing values.



**Figure 2.** Pre-cue and post-cue comparison per cue type. Note: The figure shows group means on the composite variable memory quality, which is the average score of vividness, detail, and emotional intensity. The variable is expressed on a range of 1–5. The post-cue group consists of both the visual and the odour cue conditions.

The current findings are in agreement with previous empirical research (e.g., Aggleton & Waskett, 1999; Chu & Downes, 2002; Herz & Cupchik, 1995; Willander & Larsson, 2007, 2008) and solidify support for the link between memory and olfaction. The current study contributes to the literature also by extending the existing empirical evidence for the phenomenon by eliminating important alternative explanations for the findings that odour cues yield richer memory descriptions. First, by using Chu and Downes' double-cueing methodology, we can eliminate the possibility that the activation of the concept of the odorous object (rather than the odour itself) is the driving force behind the results, because awareness of the object is held constant in all conditions. Second, the double-cueing methodology allows us to reject the *differential encoding bias hypothesis* (Chu &

Downes, 2000a, 2002), which postulates that differences arise because the memories that tend to get triggered by odour are qualitatively different from memories that are triggered by cues of other sensory modalities. Third, by ensuring that the memories used in this study were encoded before the participants were exposed to the cues, we ruled out that differential encoding bias could have affected the results of the current study. Fourth, our study goes beyond most previous studies by explicitly targeting personally meaningful AMs. Previous research has presented participants with a variety of odour objects and asked them to think of an event associated with the odour. It is, however, unlikely that such ad hoc connections between olfactory cues and AM established in a laboratory setting will have the same qualitative aspects as naturally developing links between odours and AM. In the present



**Figure 3.** Visual cue and odour cue comparison. Note: The figure shows group means on the composite variable memory quality, which is the average score of vividness, detail, and emotional intensity. The variable is expressed on a range of 1–5.  $*p < .05$ .

study, we have attempted to target more natural and qualitative odour–AM associations by using odours that are associated with childhood to elicit childhood memories.

Lastly, we add to the literature by reporting data from a high-powered design that exceeds prior studies testing the link between olfaction and AM (previous had small to moderate sample sizes:  $N = 45$ , Aggleton & Waskett, 1999;  $N = 33$ , Chu & Downes, 2000b;  $N = 42$  (study 1) and  $N = 40$  (study 2), Chu & Downes, 2002;  $N = 48$ , Goddard, Pring, & Felmingham, 2005;  $N = 93$ , Willander & Larsson, 2006;  $N = 72$ , Willander & Larsson, 2007;  $N = 64$ , Willander & Larsson, 2008).

### Limitations and perspective

The main aim of the study was to shed light on the influence that odours may have on AM retrieval. In the following, we list some limitations that future studies could benefit from. *First*, we targeted naturalistic childhood AMs that would ideally be personally meaningful to go beyond previous research. However, meaningfulness was not assessed directly. We relied on the reasoning that childhood memories are motivationally relevant (Singer & Salovey, 1993) in conjunction with the finding of high odour–childhood associations in the pilot study. Future research in this field should assess meaningfulness of the memories.

*Second*, choosing childhood AMs made it impossible for the current study to test one of the core assumptions underlying the assertion that olfactory cues are particularly potent as triggers of AM: AMs triggered by odour are old memories (see Chu & Downes, 2000b; Herz, 2004; Larsson & Willander, 2009; Miles & Berntsen, 2011; Willander & Larsson, 2006, 2007, 2008). We opted for childhood

memories as they are meaningful and motivationally relevant for individuals (Singer & Salovey, 1993), and therefore can provide a comparable memory that is unique and person-specific (as opposed to recollections of episodic facts) that solves challenge #2. Ideally, memories should allow for both: person-specificity and flexibility in terms of age of the memory.

*Third*, the LIWC results on affective content are surprising, because they showed no differences between the visual and odour conditions, while these differences did exist in the self-report items measuring emotional ladedness.<sup>6</sup> Correlations between the Likert item and the LIWC variables are low.<sup>7</sup> Reliability of the LIWC items (affect, positive emotion, and negative emotion) is good, with  $\alpha = 0.81$  for the childhood–odour measures and  $\alpha = 0.76$  for the non-childhood measures. The divergent findings for the Likert and LIWC items therefore may be related to the internal validity of either assessment. To the knowledge of the authors, no information on the validity of the Dutch LIWC currently exists, but LIWC is a tried and tested word count procedure (Tausczik & Pennebaker, 2010). A likely candidate that could explain the absence of effects found with the LIWC variables is that participants' descriptions upon which the LIWC analysis was based on may have been incomplete characterisations of the retrieved memories. In other words, people may have recalled a vivid memory but may not have provided the same vividness in the written text, thus producing descriptions that lack affective tone compared to the actual recall experience. If memory descriptions are of lower quality due to an inability to articulate experiences (which may be the case for old AMs), it may be unlikely that this problem can be solved in future research. However, it may be inspected by offering the participants more time, convenient writing methods (e.g., keyboards, not mobile devices), and by prompting them to write down everything they remember.

### Future research

In general, personal experiences with odours differ markedly per individual and are subject to cohort and contextual differences due to the (non-)availability of certain products and associated odours. Ideally, this study would have used odours that were personally relevant to the individual participant. However, that would entail that participants need to be pretested individually for those cues. This would have substantially increased the resources needed to address the lack of power of previous studies. For the present study, we have therefore opted for stimuli that are less individualised, but a sample size that exceeds the limitations of prior studies. Therefore, we searched for odours that were (a) likely to trigger associations in our target population and (b) have a high likelihood to be from the childhood period, as childhood memories are generally of importance for current motives and goals (Singer & Salovey, 1993). The odours used in the pilot study were selected because they were

expected to resonate with the Dutch target population. It is unlikely that people outside the Netherlands would be able to identify the baby powder brand (Zwitsal). Cohort and cultural effects are therefore interesting avenues for the study of odours as they allow to use the same odour among individuals that have or have not associated meaning with it (e.g., the baby powder brand Zwitsal outside the Netherlands).

The current study was designed with a unimodal cueing approach, meaning that participants were exposed to cues of only one sensory modality (either visual or olfactory). Very recently, multimodal cueing techniques have been proposed and used for the first time: Larsson et al. (2014) and Willander, Sikström, and Karlsson (2015) propose to expose participants to visual, olfactory, and auditory cues, which allow researchers to better examine differential memory retrieval. Using multimodal cueing, Willander et al. (2015) found that memory retrieval was driven primarily by visual and auditory information and to a lesser extent by olfactory information. Previous research on the link between AM and olfaction suggests that odours are more effective retrieval cues than cues of other modalities; the study by Willander et al. (2015) is not in line with our predictions.

Lastly, the current study exclusively studied salient odours. Participants were explicitly made aware of the odour and the nature of the odour, in order to eliminate the rival hypothesis that activation of the odour object, rather than the odour itself, was the driving force behind the effect. However, the results of the pilot study revealed that the strength of childhood associations did not depend on correctly identifying the content of an odour container. For example, many participants failed to correctly identify the perfumed baby powder, yet the reported strength of childhood associations for this odour was high (second only to VapoRub). This finding suggests that explicit awareness of the odour may not be a necessary requirement for odour-elicited AM, which is in line with the literature on memory retrieval, which can be generative but also direct (Conway, 2005; Conway & Pleydell-Pearce, 2000; Moscovitch, 1995). According to Larsson et al. (2014), verbal cues lead to generative search strategies where the process is intentional, elaborative, and effortful, while perceptual cues (such as odours) lead to direct recollections which are immediate and effortless. This prediction was supported by neuroanatomical research into retrieval process by Arshamian et al. (2013), who found that memory cues by words and odours both resulted in activation of brain regions generally associated with AM, but that word cues also resulted in increased activity in the pre-frontal cortex, while odour cues did not. Together, these findings show that the memory retrieval process induced by odours is much more direct and subconscious than verbal cue processes and they may explain why odours in the pilot study were able to generate the expected associations while their verbal label remained unidentified. Future research should examine the effects of non-salient

and unidentified odours on cognition, in order to increase our understanding of the mechanics behind the odour-elicited AM.

### Implications

We set out to contribute to the study of olfaction and cognition by applying a methodology suitable to directly test the assertion that odours are more effective AM cues than cues of other sensory modalities. To this end, we adapted Chu and Downes' (2002) procedure to target meaningful AMs, by identifying and using odours which can be expected to elicit similar associations in a large body of people. We believe that this approach has allowed us to provide evidence in support of the assertion that olfactory cues are particularly potent as triggers for AM.

Understanding odour-elicited AM helps us understand the effect of odours on cognition in general. Odours are ubiquitous (though not always salient). Because we can now conclude that odours facilitate the retrieval of specific memories, this facilitation of specific memory retrieval may thus also be a ubiquitous process. This realisation opens up avenues for research about self-perception, but also mood and decision-making may be influenced by the elicitation of specific (valenced) memories. The finding that odours indeed facilitate the retrieval of rich AMs may also be of interest to companies. After all, the valence of the elicited memory could influence people's attitude towards the odour object (see e.g., Bone & Jantrania, 1992). Dual processing theories such as the Elaboration Likelihood Model (Petty & Cacioppo, 1986) and the heuristic-systematic model of processing (Eagly & Chaiken, 1993) postulate that the non-effortful process of attitude formation can be influenced by heuristics such as affect ("I like this because it makes me feel good"). In the case of attitude formation and odour-elicited memories, an odorous object may elicit a specific, rich, and valenced AM. The valence could then influence a person's attitude towards the odorous object ("I like this because it makes me remember happy times"). While the mechanism underlying such an effect is speculative, it may be relevant for companies dedicated to selling odorous products: the brand of perfumed baby powder used in the pilot study may profit from fond memories of people's own childhood.

The current study on olfaction and childhood memory can also be useful for research on childhood amnesia (i.e., the inability to recall AMs before the ages of 2–4; see Bauer, Fivush, & Howe, 2013 for an overview). The phenomenon of odour-evoked AM would posit that odours are ideally suited to recall very old memories. Indeed, odour-induced memories tend to originate to the first decade of life, whereas the bulk of AM memories (cues with cues of other sensory modalities) tend to originate in early adulthood (Larsson & Willander, 2009; Willander & Larsson, 2006, 2007, 2008). This is in line with

anecdotal evidence from participants in the pilot study reporting a tip-of-the-tongue experience: they felt they recognised the odour but were unable to name it. In sum, odours may be a potent cue to access early childhood memories in particular.

## Conclusion

In conclusion, we found empirical support for the assertion that odours are more effective AM cues than cues of other sensory modalities while outlining and overcoming or avoiding the common methodological pitfalls of prior approaches. This study has replicated earlier findings about the effectiveness of odour as an AM retrieval cue, and it has showcased how we can improve the methodology of studying olfaction and memory. Further research is required to examine the cultural validity of the relationship and to determine to what extent awareness and recognition of the odour is a necessary aspect of their effectiveness as AM cues.

## Notes

1. The study by Reid et al. (2015) used (among others) pumpkin pie spice, lavender, and baby powder. Instead of pumpkin spice, the current study used cinnamon as a "holiday" odour, because the consumption of pumpkin is not as common in the Netherlands. Furthermore, this study used baby powder of the Zwitsal brand, because this brand is very well known in the Netherlands and has a distinctive odour. VapoRub and peanut butter were added by the authors.
2. There is anecdotal evidence that participants felt the task was more difficult than they had expected and that they strongly felt that they knew the odours even if they could not identify them.
3. This approach was chosen because an a priori power analysis indicated that adding a no-cue condition to the sensory modality variable would raise the power requirements for this study such that it could not realistically be realised. By asking participants to answer the pre-cue items, a no-cue baseline was created by means of a within-subjects variable (pre-cue vs. post-cue measurement), while avoiding an increase in power demands. Of course, a comparison between the pre-cue, odour cue, and visual cue conditions is possible only if there is no carry-over effect of the pre-cue measurement. Asking only half of the participants to fill in the pre-cue items allowed for a test of carry-over effects, the outcome of which can be found in the Results section of this study.
4. This study was conducted in combination with three other (unrelated) studies. These other studies commenced *after* the completion of the current study and have therefore not interfered with the results.
5. The  $p$ -value of .06 was found for the composite variable of memory descriptions, when participants were shown the non-childhood cue (vinegar) first. It is not surprising that differences in this composite approach significance, given that two out of the three items that constitute the composite variable, are significant (see below); among participants who received the vinegar memory first, scores of detail ( $t(89) = -2.11$ ,  $p = .04$ ) and vividness ( $t(89) = -1.97$ ,  $p = .05$ ) were higher for those who did answer the pre-cue items compared to those who did not. The effect was absent when no distinction was made between cue order, which suggests that the effect is

small, non-systematic, and limited. While this order effect could be spurious, conclusions concerning the non-childhood cue should be interpreted with caution.

6. We also examined differences between the individual variables *vividness*, *detail*, and *emotional intensity*. Participants in the cue conditions reported more *vividness* than participants in the no-cue condition ( $F_{\text{childhood cue}}(1, 82) = 39.78$ ,  $p < .001$  and  $F_{\text{non-childhood cue}}(1, 83) = 12.99$ ,  $p = .001$ ). An ANOVA showed that participants presented with the childhood odour ( $M_{\text{odour}} = 4.58$ ,  $SD_{\text{odour}} = 1.57$ ) reported memories of more *vividness* than participants presented with the childhood image ( $M_{\text{image}} = 3.85$ ,  $SD_{\text{image}} = 1.92$ ) ( $F(1) = 7.17$ ,  $p = .01$ ,  $\eta^2_{\text{partial}} = 0.04$ ). This effect was not found for participants presented with the non-childhood cue ( $M_{\text{odour}} = 4.20$ ,  $SD_{\text{odour}} = 1.84$ ,  $M_{\text{image}} = 3.98$ ,  $SD_{\text{image}} = 1.82$ ;  $F(1) = 0.68$ ,  $p = .41$ ,  $\eta^2_{\text{partial}} = 0.004$ ). Participants in the cue conditions reported more *detail* than participants in the no-cue condition ( $F_{\text{childhood cue}}(1, 82) = 30.17$ ,  $p < .001$  and  $F_{\text{non-childhood cue}}(1, 83) = 44.21$ ,  $p < .001$ ). However, an ANOVA showed that participants presented with the childhood odour ( $M_{\text{odour}} = 4.18$ ,  $SD_{\text{odour}} = 1.77$ ) did not report memories of more detail than participants presented with the childhood image ( $M_{\text{image}} = 3.75$ ,  $SD_{\text{image}} = 1.87$ ;  $F(1) = 1.79$ ,  $p = .18$ ,  $\eta^2_{\text{partial}} = 0.01$ ). This effect was also not found for participants who were presented with the non-childhood cue ( $M_{\text{odour}} = 4.05$ ,  $SD_{\text{odour}} = 1.83$ ,  $M_{\text{image}} = 4.11$ ,  $SD_{\text{image}} = 1.71$ ;  $F(1) = 0.11$ ,  $p = .75$ ,  $\eta^2_{\text{partial}} = 0.001$ ). Lastly, participants in the cue conditions reported more *emotional intensity* than participants in the no-cue condition ( $F_{\text{childhood cue}}(1, 82) = 33.03$ ,  $p < .001$  and  $F_{\text{non-childhood cue}}(1, 83) = 13.23$ ,  $p < .001$ ). An ANOVA showed that participants presented with the childhood odour ( $M_{\text{odour}} = 3.51$ ,  $SD_{\text{odour}} = 1.58$ ) did not report memories of more emotional intensity than participants presented with the childhood image ( $M_{\text{image}} = 3.11$ ,  $SD_{\text{image}} = 1.75$ ) ( $F(1) = 1.95$ ,  $p = .17$ ,  $\eta^2_{\text{partial}} = 0.01$ ). This effect was also not found for participants who were presented with the non-childhood cue ( $M_{\text{odour}} = 3.09$ ,  $SD_{\text{odour}} = 1.60$ ,  $M_{\text{image}} = 3.01$ ,  $SD_{\text{image}} = 1.61$ ;  $F(1) = 0.04$ ,  $p = .85$ ,  $\eta^2_{\text{partial}} < 0.001$ ). These last findings are not in line with our expectations.
7. For the childhood odour (VapoRub), correlations between the Likert item and the three LIWC items were  $r = .24$ ,  $p < .01$  for affect,  $r = .22$ ,  $p < .01$  for positive emotion, and  $r = .09$ ,  $p = .23$  for negative emotion. Among the non-childhood odour memories, correlations were  $r = .32$ ,  $p < .001$  for affect,  $r = .27$ ,  $p < .001$  for positive emotion, and  $r = .19$ ,  $p = .01$  for negative emotion.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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